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(54) Title: METHOD AND ARRANGEMENT IN A TELECOMMUNICATION SYSTEM

(57) Abstract

The invention relates to a method for lobe shifting in a telecommunication system and an arrangement in a lobe forming network, wherein a fine tuning device is arranged to achieve interpolation between fixed lobes (LF1–LFn) to create an interpolated lobe with an arbitrary direction between the fixed lobes. The fine tuning device according to the invention supports interference cancellation.

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5   APPLICANT: RADIO DESIGN AB
     TITLE OF INVENTION: METHOD AND ARRANGEMENT IN A TELE-
                           COMMUNICATION SYSTEM

10

Field of invention

The present invention relates to a method for lobe shifting in a tele-communication system and an arrangement in a lobe forming network.

15 Prior art

Figure 1 discloses a schematic diagram of a flexible lobe shaping system. The antenna array has preferably eight antenna elements.

Each frequency channel has its own set of weights (e.g. $W_1(1) - W_8(1)$ in Figure 1). The number of these weights is determined by the number of antenna
20 elements used.

The number of weight sets is determined by the number of simultaneously channels. Each frequency channel has one set of weights and if SDMA (Spatial Division Multiple Access) is used there must be several weight settings for each frequency channel.

25   No. of weight sets = No. of frequency channels × SDMA factor.

No. of complex weights = No. of frequency channels × SDMA factor × number of antenna elements.

The lobe shaping system of Figure 1 is described in detail in the pending applications 9601613-4 (Method and Arrangement of Converting a Cellular Tele-
30 communication System, Applicant: Radio Design AB), 9601615-9 (Rotating Lobe Access Method, Applicant: Radio Design AB) and 9601614-2 (Antenna System, Applicant: Radio Design AB) , which applications are incorporated herein by reference.

The flexible lobe shaping system according to Figure 1 has very high per-
35 formance. The lobes of this system can be directed towards a mobile terminal in an arbitrary direction, i.e. the direction θ of the lobe can be continously varied from 0 to 180°. It should be realized that interference cancellation by radiation pattern nulling also is possible.

However, the problem with this flexible lobe shaping system of Figure 1 is
40 that it is very expensive, i.e. too much expensive equipment is used and algorithms

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required are too advanced.

This problem may be solved by a fixed lobe shaping network as can be seen in Figure 2. Figure 2 discloses a schematic block diagram of the fixed lobe shaping network. LF1-n denotes the *n* different fixed lobes. The parts in broken lines are

5   multiple, i.e. the number of these is determined by the number of transceivers. Details of this system is disclosed in the above discussed pending applications. This solution is less hardware consuming and the algorithms are more simple since the system uses a number of fixed broadband lobes. Many mobile terminals can thereby use the same lobes. However, the number of lobes must be low since the

10   reason to introduce fixed lobes (n in Figure 2) is to reduce the amount of hardware. This implies of course a performance degradation compared to the above mentioned flexible lobe shaping system, i.e. the lobes can only be directed in fixed determined directions as can be seen in Figure 3. The degradation can be limited if a very high number of fixed lobes are formed. However, as mentioned before, the

15   number of fixed lobes must be low to reduce the amount of hardware. Interference cancellation by radiation pattern nulling is not possible with the system of Figure 2, which results in a performance degradation in comparison to the system of Figure 1. Abrupt lobe switching can interfere with the transmission. The need for resynchronization after a lobe switch due to phase disturbance is possible.

20   To summarize the situation, the flexible lobe shaping system has high lobe direction performance but is expensive and uses advanced algorithms, and the fixed lobe shaping network is cheap, uses simple algorithms but has low lobe direction performance.

The object of the present invention is to overcome the drawbacks of the

25   above discussed systems, i.e. to create a system which is cheap, uses simple algorithms, has high lobe direction performance and supports interference cancellation.

Summary of the invention

30   The above object is achieved by means of a method for lobe shifting in a telecommunication system and an arrangement in a lobe forming network as claimed in claim 1 and 9 respectively.

The method and the arrangement in accordance with the present invention have many advantages in comparision with the above discussed systems. These

35   advantages are for example:
   - simple and cheap solution;
   - simple algorithms can be used (much simpler than for the flexible lobe system);
   - tracking of the mobile terminal by the use of fine tuned fixed lobes;
40   - no abrupt lobe switching and no need for resynchronization after lobe

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switch;
- high performance (equal to the flexible lobe solution);
- interference cancellation possible (not possible in an ordinary fixed lobe system);
5   - no cross-over zone with lower gain between the lobes since the lobes can be directed in arbitrary direction;
- full steerable lobes in all directions;
- considerably reduced hardware in relation to the flexible lobe system;
- the number of lobes can be reduced compared to fixed lobe shaping
10   network.

Other characteristics of the invention are set out in the dependent claims.

Brief description of the drawings

A detailed description of the invention will now be given with reference to
15   the following drawings, of which:

Figure 1 is a schematic diagram of the flexible lobe shaping system;

Figure 2 is a schematic block diagram of a fixed lobe shaping unit;

Figure 3 discloses lobe directions of the fixed lobe shaping unit in Figure 2;

Figure 4 is a block diagram of the seamless lobe forming network in
20   accordance with the present invention;

Figure 5 discloses interpolation between fixed lobes according to the present invention;

Figure 6 discloses cancellation of a side lobe in accordance with the present invention;

25   Figure 7 is a realization on component level of the block diagram of Figure 4;

Figure 8 is a I-Q Vector Modulator.

Detailed description of an embodiment of the present invention

The invention is based on the fixed lobe shaping system, the system of which
30   uses coarse weighting of the lobe through the fixed lobe forming network. However, the invention lies in the splitter and the fine tuning device as can be seen in Figure 4. The antenna array has preferably eight antenna elements, the function of which is explained in the above mentioned pending application, Antenna System. The parts in broken lines are multiple, i.e. the number of these is determined by the
35   number of transceivers. The coarse part of Figure 4 consists of lobe shaping units, which generate lobes in fixed directions. These lobe shaping units have $\underline{8}$ fixed complex weight coefficients (magnitude- and phase weights), which coefficients are multiplied with a signal on its way to (or on its way from) each one of the antenna element. The complex weight coefficients are chosen so that the multiplied
40   signals from/to the antenna elements interact with high gain in a fixed direction,

i.e. fixed main lobe (LF1, Figure 6) and interfere with low gain in all other directions (SL1, side lobes, Figure 6). The core of the invention lies in the fine tuning device using an arbitrary number (LF1-LFn) of fixed lobes simultaneously. This results in a interpolation between the fixed lobes (LF1-LFn). This implies that there will be no need for resynchronization after lobe switch and no abrupt lobe switching will occur. Thus, the invention enables tracking of mobile terminals by the use of fine tuned fixed lobes. The invention is used both in up- and downlink. In the uplink a combiner is used and in the downlink a splitter is used. The implementation can of course differ but the inventive principle is the same.

The splitter in Figure 4 divides the effect from TRX between the inputs of the fine tuning device. Normally the effect is equally divided between the inputs of the fine tuning device. It should be realized that when TRX is receiving a combiner is used to combine the signal effect from the outputs of the fine tuning device.

The fine tuning device in Figure 4 comprises modulators. The purpose of these modulators is to modulate the phase and the amplitude of the signal. A preferable modulator is for example the I-Q vector modulator as can be seen in Figure 8. The I-Q vector modulator is a unique combination of active and passive devices that is, in theory, ideally suited for simultaneous control of amplitude and phase. The modulators (1-n) are used to achieve lobe interpolation and interference cancellation of side lobes. Instead of modulators, PIN diode attenuators can be used for lobe interpolation, However, PIN diode attenuators cannot achieve interference cancellation.

Let us assume that we will create a lobe (LF interpolation) between the fixed lobes LF1 and LF2 in Figure 5.

The signal from the splitter in Figure 4 is divided in n equally large signals, which are delivered in phase to the modulators 1-n in the fine tuning device. To create the lobe interpolation between LF1 and LF2, the attenuation of modulator 1/PIN diode attenuator 1 and modulator 2/PIN diode attenuator 2 is set to a minimum value, after which lobes LF1 and LF2 are added to create the interpolation lobe (LF interpolation) as can be seen in Figure 5. In this case, the attenuation of the other modulators 3-n/PIN diode attenuator 3-n is set to a maximum value. Thus, in order to achieve an arbitrary lobe interpolation between two different lobes (LF1 - LFn), signals in the modulators/PIN diode attenuators 1-n are amplitude modulated and the fixed lobes (LF1 – LFn) associated with the amplitude modulated signals are added together to create the lobe interpolation (LF interpolation). This transition between fixed lobes and interpolated lobes is referred to as seamless lobe shifting.

It should of course be realized that the signal from the splitter can be divided equally or unequally to the modulators 1-n in the fine tuning device. This implies that you can combine an arbitrary number of lobes (LF1-LFn), e.g. lobes LF1, LF3,

LF4, LF6 and LFn, to create an optional antenna pattern, e.g. a wide lobe.

The lobe forming network in Figure 4 can also be used for interference cancellation as can be seen in Figure 6 provided that a phase-modulator is used, for example an I-Q vector modulator (Figure 8). By adjusting the phase and amplitude

5   of the weights, one fixed lobe can be used to suppress the radiation pattern of another lobe.

Interference cancellation will now be described by way of an example with reference to Figure 6. Figure 6A discloses a situation where a mobile terminal MT1 uses the channel of LF1 for communication with the base station. Side lobe SL1

10 originating from main lobe LF1 disturbs the mobile terminal MT2 which is communicating on the same channel. In this case most of the signal effect is distributed in the fixed lobe LF1. In order to suppress side lobe SL1 the signal of for example modulator 4 in the fine tuning device of Figure 4 is phase- and amplitude modulated so that the lobe LF4 associated with said modulated signal has the same

15 amplitude as side lobe SL1 but is in counterphase (180° phase shifted) in relation to side lobe SL1 as may be seen in Figure 6B. It should of course be appreciated that lobe LF4 radiates in the same direction as side lobe SL1 but is in counterphase in relation to lobe SL1 implying an interference cancellation. This cancellation is only figuratively disclosed in Figure 6B. Thus, by phase- (180°) and amplitude

20 modulating the signal in modulator 4, the lobe LF4 will suppress the side lobe SL1 and the side lobe SL1 will be eliminated as can be seen in Figure 6C. Thus, in Figure 6C the mobile terminal MT2 does not disturb MT1 and vice versa, since the side lobe SL1 has been suppressed.

Figure 7 is a circuit diagram of the invention in accordance with Figure 4.

25 Figure 7 discloses a system with two TRX (10, 20, transmitter/receiver), four fixed lobes and four dipole columns per antenna. It should of course be realized that an arbitrary number of TRX, lobes and dipole columns could be used. The splitter 11 is preferably an ordinary Wilkinson splitter/combiner, which is described in Microwave Transistor Amplifiers, Guillermo Gonzales ISDN O-13-254 335-4. It

30 should be emphasized that the splitter 11 can be used for both splitting and combining due to transmission or reception of radio signals. In Figure 7 the signal is divided by four in the splitter 11. The modulators 12 are PIN diode attenuators or vector modulators as described above. The modulators 12 are connected to combiners 16 combining signals from the two TRX 10, 20. The combiners 16 are

35 connected to dividers 13 which divide the signals by a factor 4. The dividers 13 are connected to a delay line and fixed attenuators 14 or vector modulators 14, which in turn are connected to combiners 15. Combiners 15 are connected to amplifiers 17. The signals from combiners 15 are amplified in amplifiers 17 and are then fed to the antenna element 19 via the duplex filter 18 for transmission. In principle, the

40 same system (slightly modified) is used for the reception of radio signals.

The above mentioned is only to be considered as an advantageous embodiment of the present invention, and the scope of the invention is given by the following claims.

CLAIMS

1. A method for lobe shifting in a telecommunication system, **characterized** in that a combination of lobes (LF1-LFn) is used to create an arbitrary antenna pattern.

5   2. A method as claimed in claim 1, **characterized** in that said arbitrary antenna pattern is used to suppress arbitrary side lobes (SL1).

3. A method as claimed in claim 1 or 2, **characterized** in that said combination is an interpolation between fixed lobes (LF1-LFn)

4. A method as claimed in claim 3, **characterized** in that said interpolation is

10   used between fixed lobes (LF1–LFn) to create an interpolated lobe (LF interpolation) with an arbitrary direction between said fixed lobes (LF1–LFn).

5. A method as claimed in claim 4, **characterized** in that said interpolation between said fixed lobes (LF1-LFn) is achieved by the addition of said fixed lobes, which creates said interpolated lobe (LF interpolation).

15   6. A method as claimed in claim 5, **characterized** in that said interpolation (LF interpolation) between fixed lobes (LF1, LF2) is achieved by the steps of:

- amplitude-modulating signals associated with said fixed lobes (LF1, LF2);
- adding said fixed lobes (LF1, LF2) together.

7. A method as claimed in claim 6, **characterized** in that a fine tuning device

20   is used to achieve said amplitude modulation of said signals, associated with said fixed lobes (LF1, LF2), by adjusting amplitude weight coefficients.

8. A method as claimed in any of claims 3-7, **characterized** in that an interference cancellation is achieved by adjusting phase- and amplitude weight coefficients associated with at least one fixed lobe (LF4), which at least one fixed

25   lobe (LF4) is used to suppress the radiation pattern of other lobes (SL1).

9. An arrangement in a lobe forming network, **characterized** in that a fine tuning device is arranged to combine lobes (LF1-LFn) with each other to create an arbitrary antenna pattern.

10. An arrangement as claimed in claim 9, **characterized** in that said arbi-

30   trary antenna pattern is used to suppress arbitrary side lobes (SL1).

11. An arrangement as claimed in any of claims 9 or 10, **characterized** in that said combination is an interpolation between fixed lobes (LF1-LFn).

12. An arrangement as claimed in claim 11, **characterized** in that a fine tuning device is arranged to achieve interpolation between fixed lobes (LF1-LFn)

35   to create an interpolated lobe (LF interpolation) with an arbitrary direction between said fixed lobes (LF1-LFn).

13. An arrangement as claimed in claim 12, **characterized** in that said fine tuning device comprises modulators (1-n) arranged to amplitude-modulate signals associated with said fixed lobes, wherein said fixed lobes (LF1-LFn) are added

40   together in an adder to form said interpolated lobe (LF interpolation).

14. An arrangement as claimed in claim 13, **characterized** in that said modulators (1-n) adjust amplitude weight coefficients associated with said fixed lobes (LF1, LF2) in order to create said interpolated lobe (LF interpolation) between said fixed lobes (LF1, LF2).

5   15. An arrangement as claimed in claim 14, **characterized** in that a splitter divides signals from a TRX in equally large signals (n), which equally large signals (n) are delivered in phase to said modulators (1-n) in said fine tuning device.

16. An arrangement as claimed in any of claims 13-15, **characterized** in that said modulators (1-n) modulate the amplitude- and the phase weight coefficients

10   associated with said fixed lobes.

17. An arrangement as claimed in claim 16, **characterized** in that said modulators are I-Q vector modulators.

18. An arrangement as claimed in any of claims 13-15, **characterized** in that said modulators are PIN-diode attenuators.

15   19. An arrangement as claimed in any of claims 11, 16-17, **characterized** in that said modulators adjust the phase- and amplitude weight coefficients which coefficients correspond to fixed lobes (LF4), wherein said fixed lobes (LF4) are used to suppress the radiation pattern of lobes (SL1), preferably interfering side lobes.

20   20. An arrangement as claimed in claim 19, **characterized** in that a modulator (4) in said fine tuning device adjusts its phase- and amplitude weight coefficients in order to phase- and amplitude modulate a signal associated with a fixed lobe (LF4), wherein said fixed lobe (LF4) is used to suppress a side lobe (SL1).
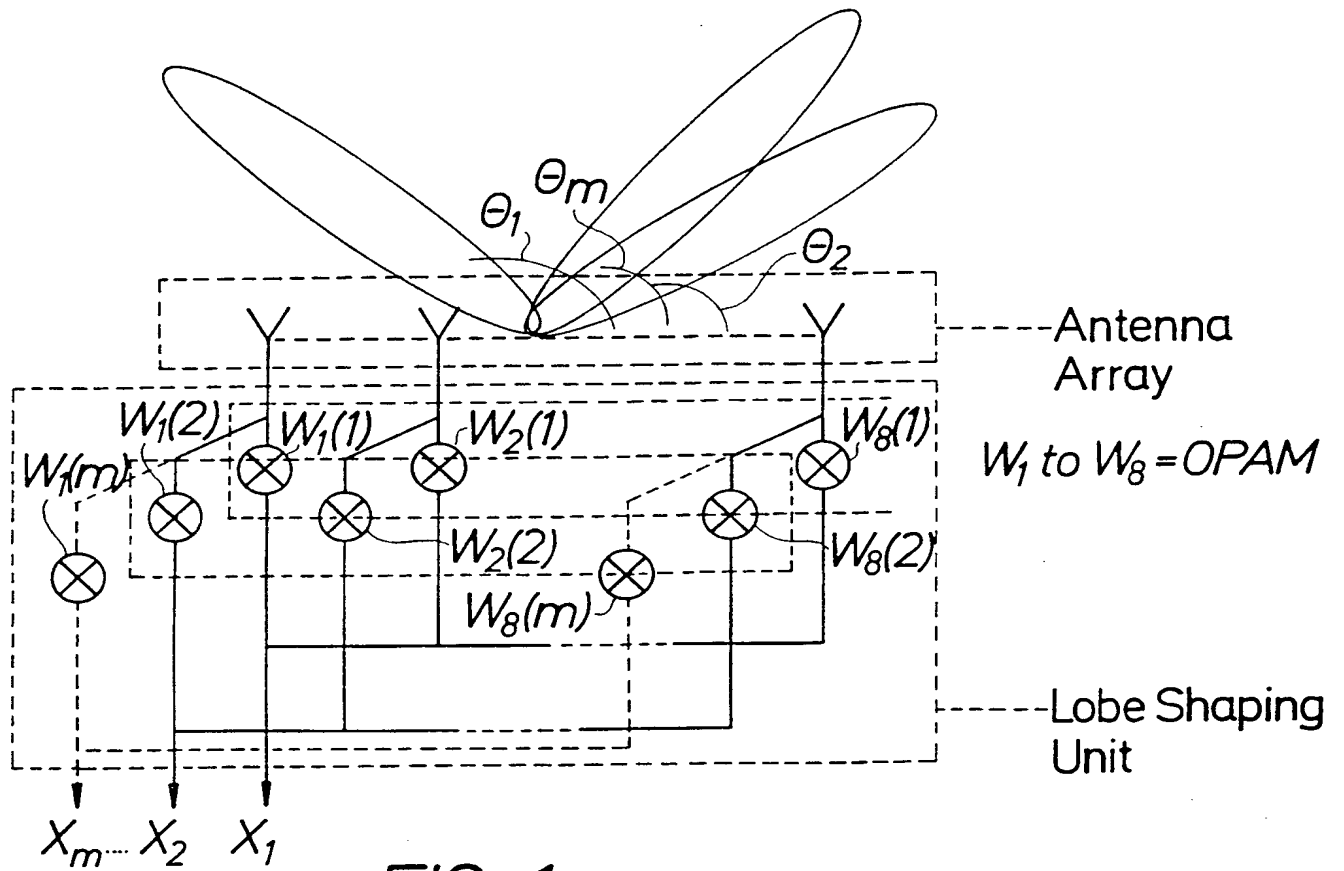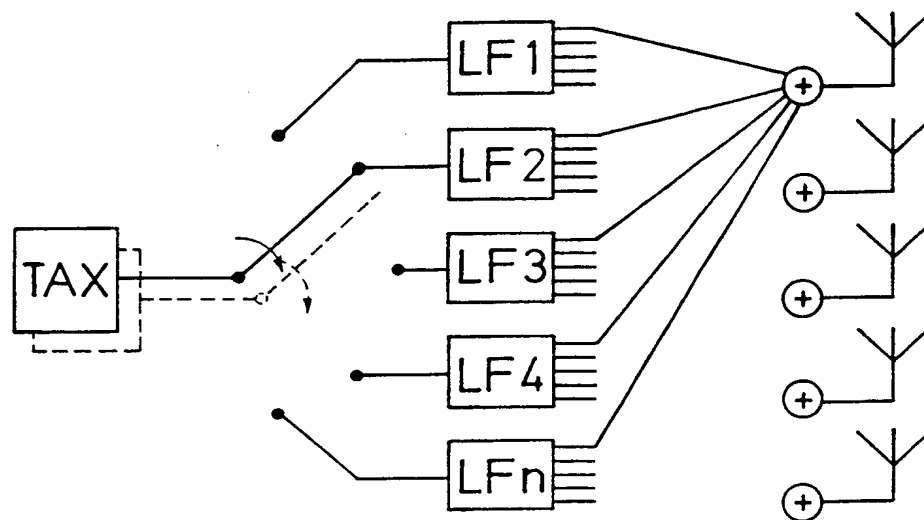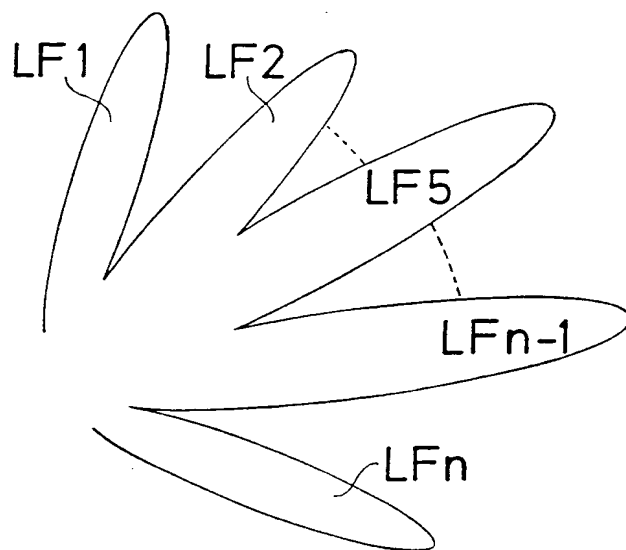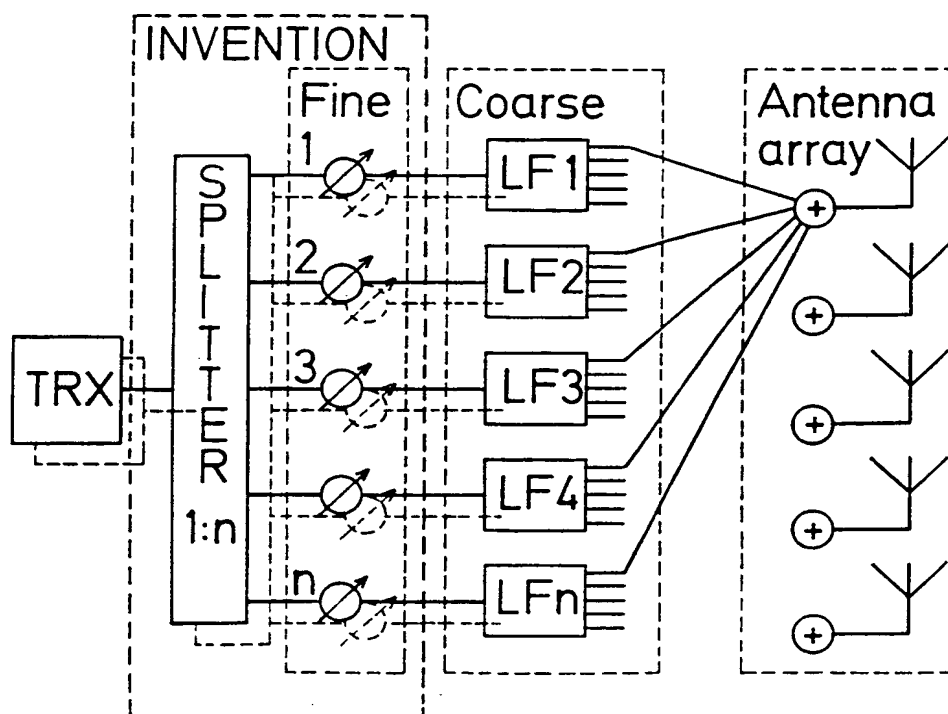
FIG. 1

FIG. 2

FIG. 3

FIG. 4

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LF1

LF interpolation

LF2

LFn

FIG. 5

MT1

LF1

MT2

SL1

FIG. 6A

MT1

LF1

MT2

SL1

LF4

FIG. 6B

MT1

LF1

MT2

FIG. 6C
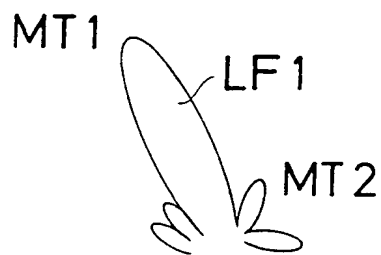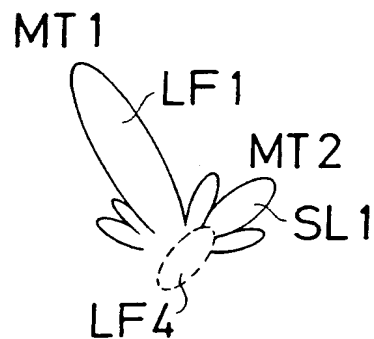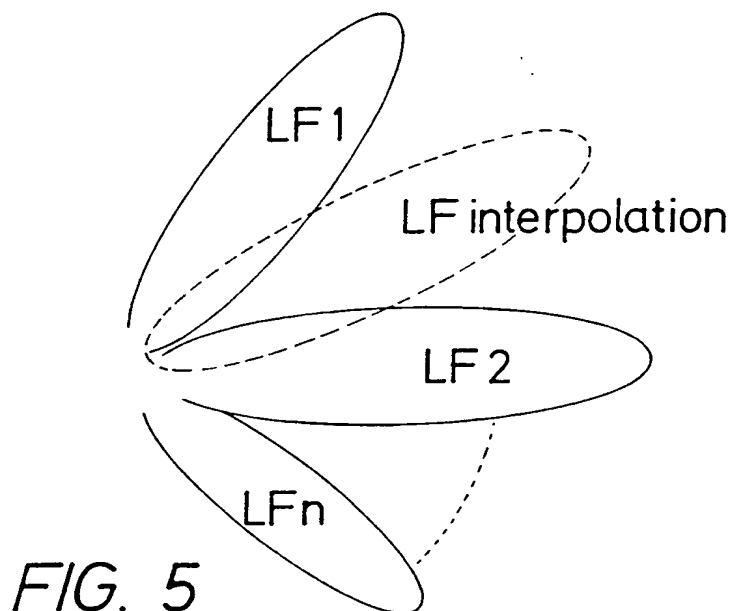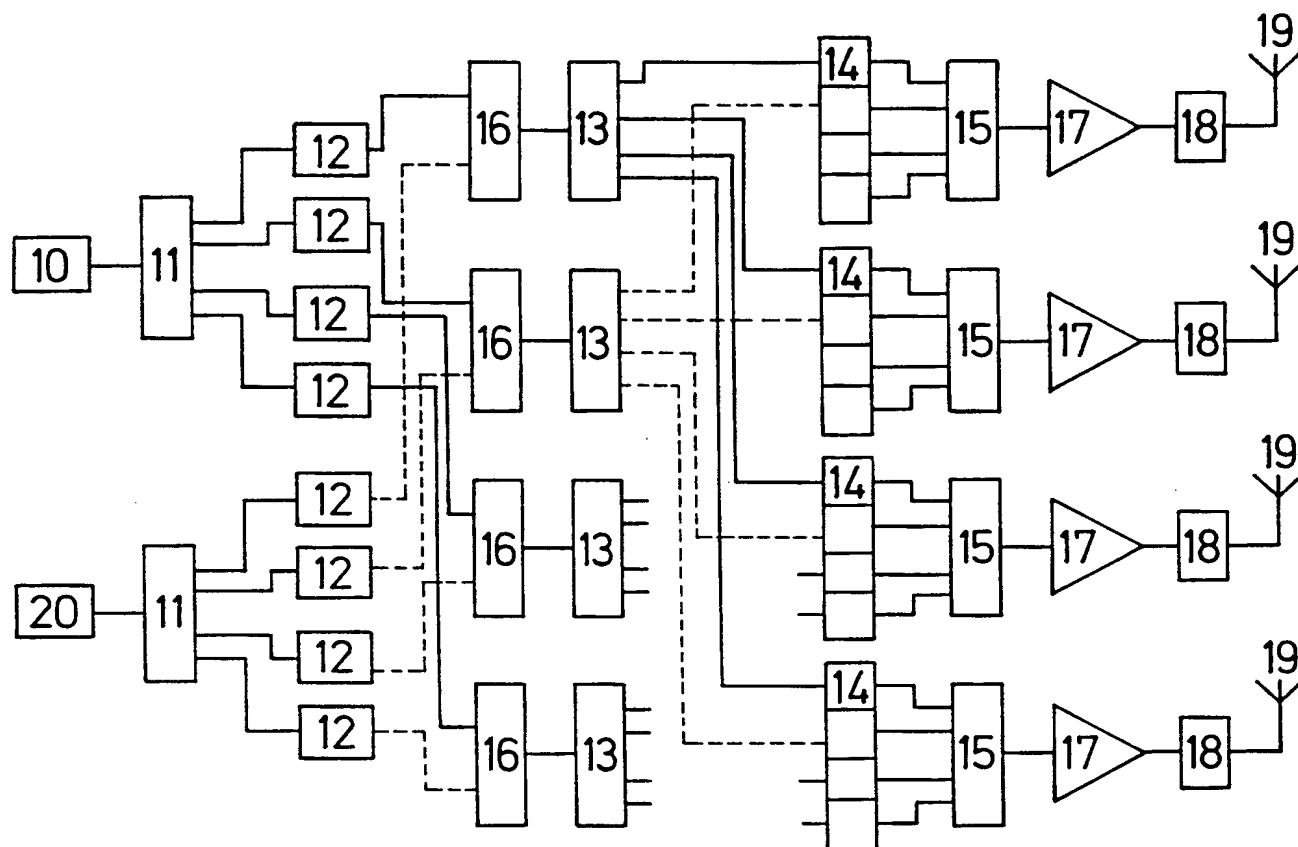
FIG. 7
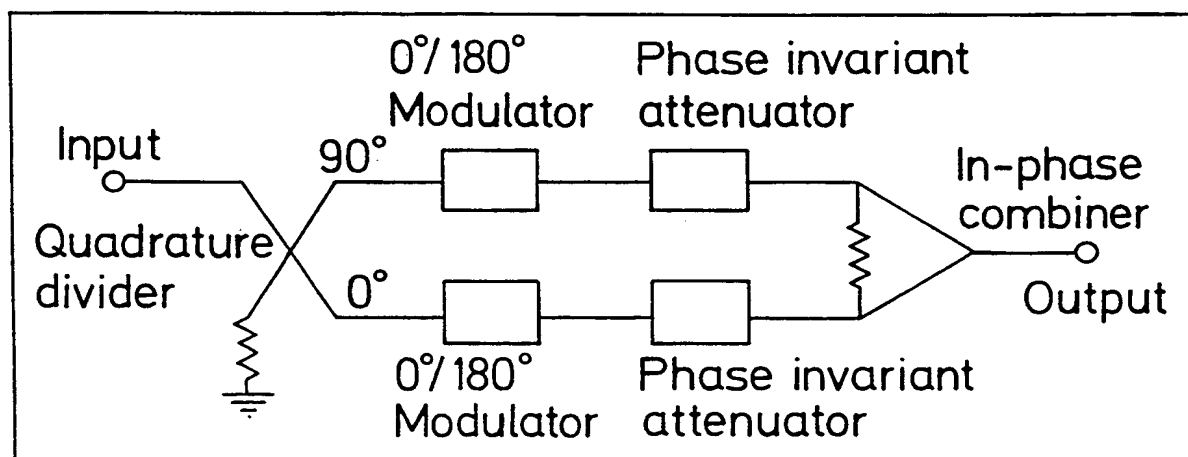
FIG. 8

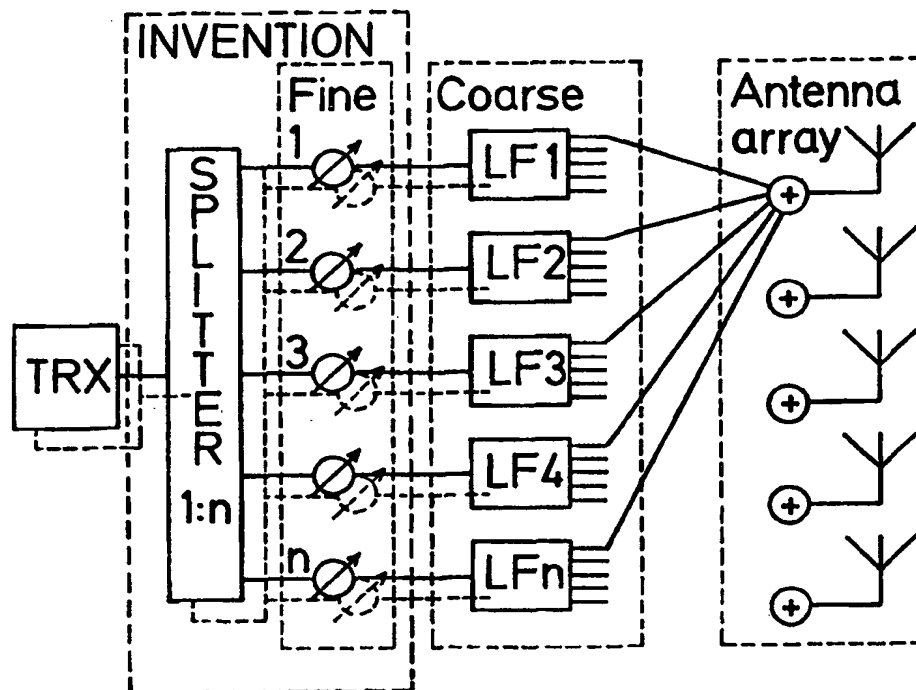## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 98/01892

A. CLASSIFICATION OF SUBJECT MATTER

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IPC6: H04B, H01Q, H04Q

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X	WO 9741705 A1 (RADIO DESIGN INNOVATION AB), 6 November 1997 (06.11.97), page 4, line 13 - line 33	1-6,8
A	--	7,9-20

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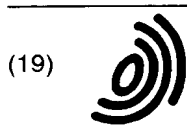
(12) EUROPEAN PATENT APPLICATION

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(54) Nulling direct radiating array

(57)   A nulling direct radiating array (30) that includes a main phased array (32) and a plurality of auxiliary arrays (70, 72, 74) symmetrically disposed about the main array (32). The main array (32) includes a plurality of antenna elements (34) and a beam forming system (56) that generates one or more channels made up of several pixel beams. The pixel beams from the main array (32) are connected to a nulling processor (108) along with the combined signal from the antenna elements (80) of the auxiliary arrays (70, 72, 74). An adaptive weighting network (112) and an adaptive weight generator (114) within the nulling processor (108) determine whether a jamming signal exists in the channel beam, and weight the pixel beams from the main array (32) accordingly to block the jamming signal. The auxiliary arrays (70, 72, 74) provide a wider beam aperture that is able to more narrowly define the null in the radiation pattern of the main array (32).
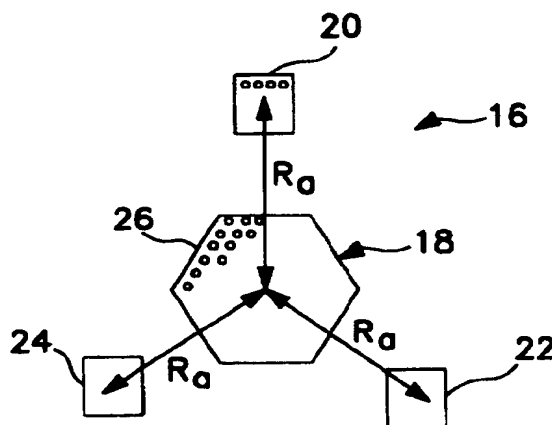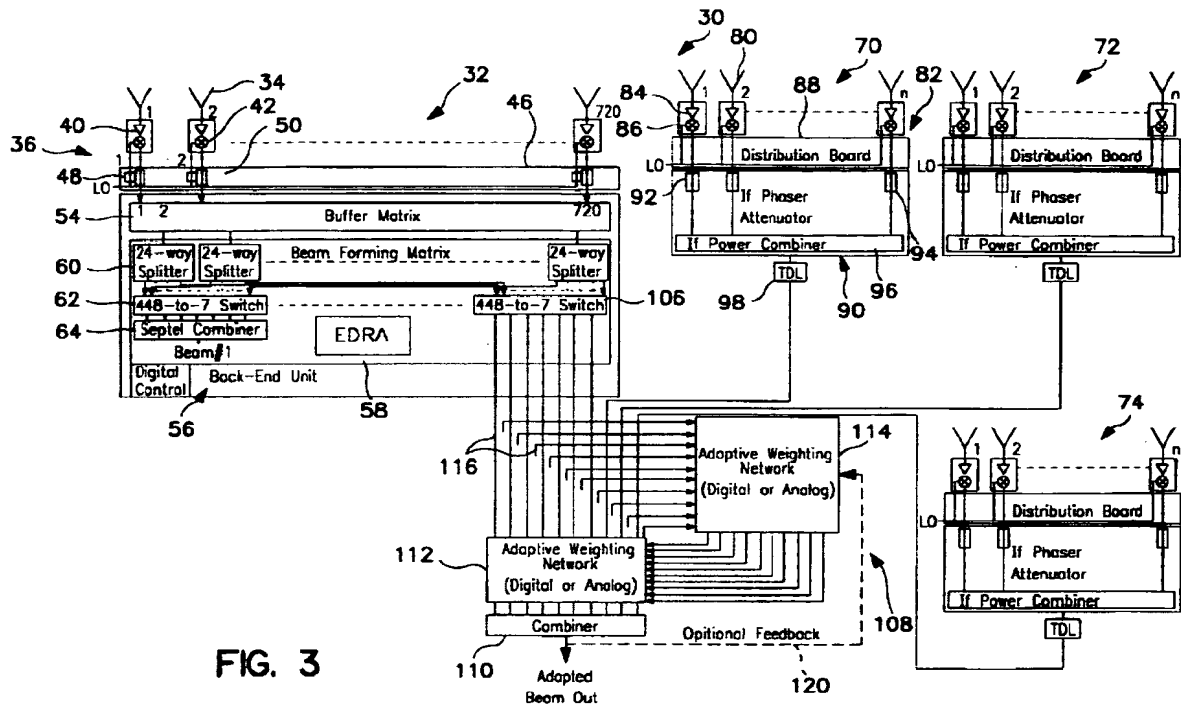
FIG. 2

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FIG. 3

Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] This invention relates generally to a nulling antenna system and, more particularly, to a nulling direct radiating array antenna that employs auxiliary antenna arrays positioned around a main array for increasing the nulling resolution.

2. Discussion of the Related Art

[0002] Various communications systems, such as certain telephone systems, cable television systems, internet systems, and military communications systems, make use of satellites orbiting the Earth to transfer communication signals. A satellite uplink communications signal is transmitted to the satellite from one or more ground stations, and the satellite retransmits the signal to another satellite or to the Earth as a downlink communications signal to cover a desirable reception area depending on the particular use. The satellite is equipped with an antenna system including an array of antenna feeds that receive the uplink signals and transmit the downlink signals to the Earth.

[0003] Satellite-based phased array antenna systems have been developed that provide signals to communication areas using pixel beams designed to cover specific areas on the Earth's surface. Typically, the pixel beams are organized into a matrix of evenly shaped and spaced beams to provide a total coverage area for a large geographical area, such as the visible Earth. One particular phased array suitable for this purpose is the "Enhanced Direct Radiating Array" disclosed in U.S. Patent Application Serial No. 09/443,526, filed November 19,1999, assigned to the assignee of this application and herein incorporated by reference.

[0004] Figure 1 is a hexagonal coverage area 10 including cells 12 defined by a phased array antenna system, where each cell 12 represents a pixel beam. The antenna system may provide a plurality of communications channels where each channel includes a plurality of pixel beams. In this example, each channel includes a hexagonal group 14 of seven cells 12, where each cell 12 in each group 14 is labeled A-G. The particular user may be located in the center cell 12 of the group 14, where the perimeter cells 12 in the group 14 provide for increased communications performance. Communications signals from locations in the group 14 are received by the antenna system on the satellite, and then retransmitted to another group 14 for communications purposes. The phased array antenna system provides beam steering for all of the groups 14.

[0005] Intentional and unintentional jamming of satellite uplink signals occurs in various situations. For example, in a military situation, satellite communications are used to transmit signals and information to and from a warfare theatre or hostile environment. The reception area for the uplink communications signals in the hostile environment may be jammed by the enemy using a high powered transmitter. If the jamming signal comes from with-in the channel area for the uplink signal, it is referred to as in-beam jamming, and if it comes from outside of the channel area for the uplink signal, it is referred to as out-of-beam jamming. The jamming signal must be at the frequency of the uplink signal to be effective for jamming purposes. Jamming signals can also come from unintentional or friendly sources that inadvertently interfere with the satellite uplink signals.

[0006] In order to eliminate or reduce the effects of jamming signals in both hostile and friendly scenarios, it is known to employ nulling antenna systems that detect the presence of a jamming signal, and provide an antenna null in the antenna radiation or reception pattern so that the jamming signal does not significantly affect the uplink signal. Particularly, nulling antenna systems are able to determine the direction of the jamming signal and create a null or void in the radiation pattern of the antenna so that it in effect does not see the jamming signal. In order to be able to block or null the jamming signal so that it does not affect the ability to transmit the downlink signal, it is necessary to determine the location of the signal, whether it be from an in-beam or out-of-beam jamming source, and then provide the null at that location.

[0007] An adaptive weighting system is generally used in nulling antenna systems to sample the received pixel beams in a particular channel to determine if a jamming signal is present. The weighting system then weights the pixel beams in the channel to block the jamming signal. The weighting system generally includes a correlator to correlate each of the pixel beams with the combined beam for the channel to determine if a jamming signal is present. Once the correlator determines that a jamming signal is present, algorithms are used to determine the location of the jamming signal. The algorithm goes through each pixel beam separately using a weighting function to determine where the jamming signal is being received from. The weighting function provides the null by inverting the phase of the received signal at the appropriate location. When the weighting of the pixel beams blocks the jamming signal and the image is cleared up, the antenna system knows where the jamming signal is being received from, and can make weighting adjustments accordingly. Various algorithms that perform this function are known to those skilled in the art.

[0008] The nulled area of the radiation pattern of the antenna has a width and a depth which determines its effectiveness in nulling the jamming signal. However, creating a null in the radiation pattern of the antenna also creates a "blind spot" in the uplink signal. Therefore, it is desirable to limit the size of the null while still blocking the jamming signal. In other words, it would be

desirable to provide higher nulling resolution to tightly define the null in the radiation pattern so that more of the uplink signal can be processed by the antenna system. This would minimize the area of the radiation pattern that is nulled, and still provide effective anti-jamming. In this manner, it is possible to provide communication to a wider area around the jamming source.

[0009]   It is known by antenna theory to narrow the antenna radiation pattern by increasing the aperture size of the antenna, i.e., providing more antenna elements. However, adding more antenna elements to increase the aperture size significantly increases the cost and complexity of the antenna system. It would be desirable to increase the aperture of the nulling antenna, without significantly increasing the number of elements to provide more effective nulling capabilities. It is therefore an objection of the present invention to provide such a nulling antenna.

SUMMARY OF THE INVENTION

[0010]   In accordance with the teachings of the present invention, a nulling direct radiating array is disclosed that includes a main phased array and a plurality of auxiliary arrays symmetrically disposed around and spaced apart from the main array. The main array includes a plurality of antenna elements and a beam forming system that generates one or more channels made up of pixel beams. The pixel beams from the main array are connected to a nulling processor along with the combined signal from the antenna elements of the auxiliary arrays. An adaptive weighting network and an adaptive weight generator within the nulling processor determine whether a jamming signal exists in the channel, and weights the pixel beams from the main array accordingly to block the jamming signal. The auxiliary arrays provide a wider beam aperture that is able to more narrowly define the null in the radiation pattern of the main array.

[0011]   Additional objects, features and advantages of the present invention will become apparent from the following description and appended claims, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012]

Figure 1 is a plurality of satellite pixel beam cells arranged in a particular field-of-view pattern;
Figure 2 is a plan view of an antenna system including an EDRA and a plurality of auxiliary arrays, according to an embodiment of the present invention;
Figure 3 is a schematic block diagram of a nulling direct radiating array, according to an embodiment of the present invention; and
Figure 4 is a schematic block diagram of a nulling direct radiating antenna, according to another embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0013]   The following discussion of the preferred embodiments directed to a nulling direct radiating array is merely exemplary in nature, and is in no way intended to limit the invention or its applications or uses. For example, the discussion below of the nulling direct radiating array is for satellite communication purposes, but as will be appreciated by those skilled in the art, can be used for anti-jamming purposes in other types of communication systems.

[0014]   Figure 2 is a plan view of a nulling antenna system 16 including an EDRA 18 and auxiliary antenna arrays 20-24 symmetrically positioned around the EDRA 18. Each of the arrays 18-24 includes a plurality of antenna elements 26, some of which are shown here. The EDRA 18 is used for receiving and transmitting communications signals to and from the Earth, and the combination of the EDRA 18 and the auxiliary antenna arrays 20-24 is used as a nulling array for anti-jamming purposes. In this example, the EDRA 18 is hexagonal in shape and the arrays 20-24 are square in shape. However, for different applications, the EDRA 18 and the arrays 20-24 can have other shapes. The arrays 20-24 are provided a certain radius R_a away from the center of the EDRA 18. In one example, R_a is about the diameter of the EDRA 18, but can be other values depending on the particular application. Additionally, the arrays 20-24 are positioned symmetrically around the EDRA 18 for performance purposes. More or less auxiliary arrays 20-24 can be provided, but at system expense or performance.

[0015]   The wider the aperture of an antenna, the narrower its radiation and reception pattern. In order to provide a nulling radiation pattern that only nulls the specific location in a communications radiation pattern where a jamming signal is located and doesn't significantly interfere with the communications signal at other locations, it is necessary that the nulling radiation pattern be narrow. To accomplish this, it is desirable to increase the aperture width of the nulling antenna arrays. A channel group 14 is identified around a particular communications user on the Earth by the EDRA 18. The radiation pattern of the nulling array is directed towards the jamming signal identified within that group 14 if it is in-beam jamming, and out of the group 14 if it is out-of-beam jamming. The nulling radiation pattern is subtracted from the communications radiation pattern by inverting its phase so that the jamming signal is nulled from the communications signal.

[0016]   Figure 3 is a schematic block diagram of a nulling antenna array system 30, according to an embodiment of the present invention. The system 30 includes an EDRA 32 of the type discussed above. In this example, the EDRA has 720 antenna elements 34, and provides a full Earth field-of-view. The EDRA 32 receives uplink communications signals from the Earth, and pro-

vides phase weighting and beam steering of the received signals to combine a certain number of the signals into pixel beams directed in a certain direction. In this example, seven pixel beams combine to form one communications channel. Each channel defines a group 14 on the Earth.

[0017] Each antenna element 34 is connected to a receiver front end 36. The front end 36 includes a low noise amplifier (LNA) 40 that amplifies the received signal. The amplified signal is applied to a mixer 42 for frequency down-conversion purposes to an intermediate frequency (IF). A local oscillator (LO) signal is applied to a distribution board 46 that distributes the LO signal to each of the mixers 42 to be mixed with the amplified signal. In order to maintain coherence between all of the mixers 42, the distribution board 46 further includes phase shifters 48 that align the LO signals in phase prior to the LO signals being applied to the mixers 42. The down-converted IF signals from the mixers 42 are applied to an attenuator 50 within the distribution board 46. The attenuators 50 provide amplitude tapering to control beam side lobes, as is well understood in the art.

[0018] The down-converted signals from the antenna elements 34 are then applied to a back end unit 56. The back end unit 56 performs beam steering functions in three steps. A Butler matrix 54 receives the down-converted antenna element signals and converts them to a plurality of pixel beams. In other words, the Butler matrix 54 converts the received signals from an element space to a beam space to allow the EDRA 32 to receive signals anywhere on the Earth. In this example, the Butler matrix 54 transforms the 720 antenna element signals into 448 pixel beams. The Butler matrix 54 also provides phase combining of the antenna element signals.

[0019] Each of the pixel beams from the Butler matrix 54 is then applied to a separate 24-way splitter 60 in a beam forming matrix 58. Each of the 24-way splitters 60 splits its pixel beam twenty-four times and sends a separate one of the beams to a 448-to-7 switch 62. Each switch 62 receives one pixel beam from each splitter 60 to combine the pixel beams into 24 seven beam channels. The seven pixel beam outputs from each switch 62 are applied to a combiner 64 that combines the signals into a single beam channel. A more detailed discussion of the operation of the EDRA can be found in the '526 application referred to above.

[0020] According to the present invention, the nulling antenna array system 30 includes three conventional phased arrays (CPAs) 70, 72 and 74, representing the auxiliary arrays 20-24 above. Only the CPA 70 will be discussed herein, with the understanding that the other arrays 72 and 74 operate in the same manner. The CPA 70 includes a plurality of antenna elements 80. In one embodiment, there are one-tenth the number of antenna elements in the CPAs 70-74 as there are in the EDRA 32. However, this is by way of a non-limiting example in that the number of antenna elements in the CPAs 70-74, as well as the actual number of CPAs, may be different

for different applications. A front end 82 of the array 70 includes an LNA 84 and a mixer 86 that operate in the same manner as discussed above. An LO signal is applied to a distribution board 88 that distributes the LO signal to the mixers 86 to convert the high frequency signals received by the elements 80 into intermediate frequency signals.

[0021] Beam steering is provided in a receiver back-end 90 by IF phasers 92. The IF phasers 92 provide the relative phase differences between the various antenna elements 82 so that the signals received from anywhere on the Earth are in phase relationship to each other. Attenuators 94 provide tapering for side lobe control, and IF power combiners 96 combine all of the received signals into a single combined signal. Because the CPAs 70-74 are relatively far apart, additional phase delaying may be necessary.

Therefore, a time delay line (TDL) 98 is provided to delay the combined signal from the combiners 96 so that the signals from the CPAs 70-74 are aligned in phase. In other words, the TDL 98 provides phase alignment for signals that are greater than 360° apart.

[0022] In this example, only one of the 24 channels from the EDRA 32 is capable of providing nulling. Particularly, the seven pixel beams from the switch 106 and the combined beams from the CPAs 70-74 are hard-wired to a nulling processor 108. The processor 108 includes an adaptive weighting network 112 and an adaptive weight generator 114. The pixel beams from the switch 106 and the combined signals from each of the combiners 96 in the CPAs 70-74 are applied as ten inputs to the adaptive weighting network 112. Ten signal couplers 116 are provided to couple a portion of the signals off of each line applied to the adaptive weighting network 112 and apply the coupled signal to the adaptive weight generator 114. The seven pixel beams from the switch 106 that make up the communications channel are separated and combined in the adaptive weighting network 112. A combiner 110 for the nulling array combines the seven pixel beams from the switch 106 and the auxiliary beams from the arrays 70-74.

[0023] The adaptive weight generator 114 goes through a known mathematical algorithm to determine if a jamming signal does exist, and if so where it is located. The adaptive weight generator 114 provides a weighting for each input line based on this determination that is applied to the adaptive weighting network 112. For example, if the adaptive weight network determines that a jamming signal is on one of the pixel beams from the switch 106, it will weight that line to zero so that it does not influence the overall signal. Any combination of pixel beams can be weighted in this manner. The adaptive weighting network 12 provides the adaptive weighting by inverting the phase of the nulling signal and combining it with the communications signal on the channel from the switch 106 so that the jamming signal is nulled.

[0024] The adaptive weighting network 112 receives

the weighting from the adaptive weight generator 114 and applies the weighting on the received signals from the switch 106 and the CPAs 70-74. An optional feedback path 120 can be applied from the combined output of the combiner 110 to the adaptive weight generator 114 so the adaptive weight generator 114 establishes that the jamming signal has in fact been nulled. The signal outputs from the adaptive weighting network 112 are applied to the combiner 110 that provides the weighted beam output. The adaptive weighting network 112 and the adaptive weight generator 114 can be digital or analog depending on the particular embodiment. The discussion above of the nulling processor 108 is by way of example. The present invention can use any suitable nulling processing known in the art.

[0025]   The discussion above with reference to the nulling antenna array system 30 only nulls one of the 24 channels from the EDRA 32. In an alternate embodiment, any number of the available channels can have nulling capabilities. To show this embodiment, figure 4 depicts a general nulling antenna array system 130 that provides nulling capabilities for each of the channels from the EDRA 32. In the system 130, like components to the system 30 are identified with the same reference numeral. In this embodiment, there are M number of channels, where K number of pixel beams make up a channel. The number of channels is general, so that the 24-way splitters 60 are replaced with M-way splitters 134. Likewise, because each M channel includes K number of pixel beams, the switches 62 have been replaced with 448-to-K switches 136. Further, the number of auxiliary arrays is general so there are N number of auxiliary arrays 132.

[0026]   Each of the switches 136 is attached to a nulling processor 108 in the same manner as the switch 106 above. Further, each array 132 includes M number of back-ends 90, one for each M channel, where the signals from the distribution board 82 are split by an M-way splitter 140. A combined output from the array 132 is provided to each nulling processor 108, where each combined output is applied to a TDL 98. Therefore, each M channel from the back-end unit 56 can be nulled separately.

[0027]   The foregoing discussion discloses and describes merely embodiments of the present invention. One skilled in the art will readily recognize from such discussion and from the accompanying drawings and claims that various changes, modifications and variations can be made therein without departing from the spirit and scope of the invention as defined in the following claims.

Claims

1.   A nulling antenna system comprising:

      a main phased array including a plurality of an-

tenna elements, said main phased array combining signals received by the antenna elements into a plurality of pixel beams, said plurality of pixel beams defining at least one communications channel;
a plurality of auxiliary phased arrays positioned around and spaced from the main array, each of the auxiliary phased arrays including a plurality of antenna elements, each of the auxiliary arrays combining signals received by the auxiliary antenna elements into an auxiliary beam; and
at least one adaptive weighting system responsive to a plurality of pixel beams defining the at least one communications channel and the plurality of auxiliary beams from the auxiliary arrays, said adaptive weighting system determining if a jamming signal is being received by the main array and weighting the pixel beams so that the jamming signal is nulled from the at least one channel.

2.   The system according to claim 1 wherein the distance between the center of the main array and the center of the auxiliary arrays is about the diameter of the combination of elements in the main array.

3.   The system according to claim 1 wherein the elements in the main array are arranged in a hexagonal configuration.

4.   The system according to claim 1 wherein the at least one adaptive weighting system includes an adaptive weighting network and an adaptive weight generator, said adaptive weight generator sampling a portion of the pixel beams and the auxiliary beams, and determining the existence and location of the jamming signal, said weight generator providing signals to the weighting network to weight the pixel beams to null the jamming signal.

5.   The system according to claim 1 wherein the at least one adaptive weighting system includes an adaptive weighting system for each of a plurality of communications channels.

6.   The system according to claim 5 wherein each auxiliary array includes a splitter or separating the auxiliary beams into separate auxiliary beams for each adaptive weighting system.

7.   The system according to claim 1 wherein the main array is an enhanced direct radiating array and the auxiliary arrays are conventional phased arrays.

8.   The system according to claim 1 wherein each auxiliary array includes a time delay device to align the auxiliary beams with each other in time.

9. A nulling antenna system comprising a main array
including a plurality of antenna elements arranged
in a predetermined configuration and comprising a
plurality of auxiliary arrays including a plurality of
antenna elements arranged in a predetermined
configuration, said auxiliary arrays being symmetri-
cally positioned around the main array and being
spaced therefrom.

10. The system according to claim 9 wherein the ele-
ments in the main array are arranged in a hexagonal
configuration.

11. A method of nulling a jamming signal received by a
communications antenna array, said method com-
prising the steps of:

    positioning a plurality of auxiliary antenna ar-
rays around the communications array and
spaced therefrom to provide a nulling array;
sampling a plurality of pixel beams from the
communications array and a plurality of auxil-
iary beams from the auxiliary arrays to deter-
mine if the jamming signal is being received by
the communications array; and
weighting the pixel beams to null the jamming
signal if the jamming signal is being received.

12. The method according to claim 11 wherein the com-
munications antenna array is an enhanced direct
radiating array, and the step of positioning a plurality
of auxiliary antenna arrays includes positioning a
plurality of conventional phased antenna arrays.

13. The method according to claim 11 wherein the step
of weighting the pixel beams to null the jamming sig-
nal includes employing an adaptive weighting net-
work and an adaptive weight generator to detect the
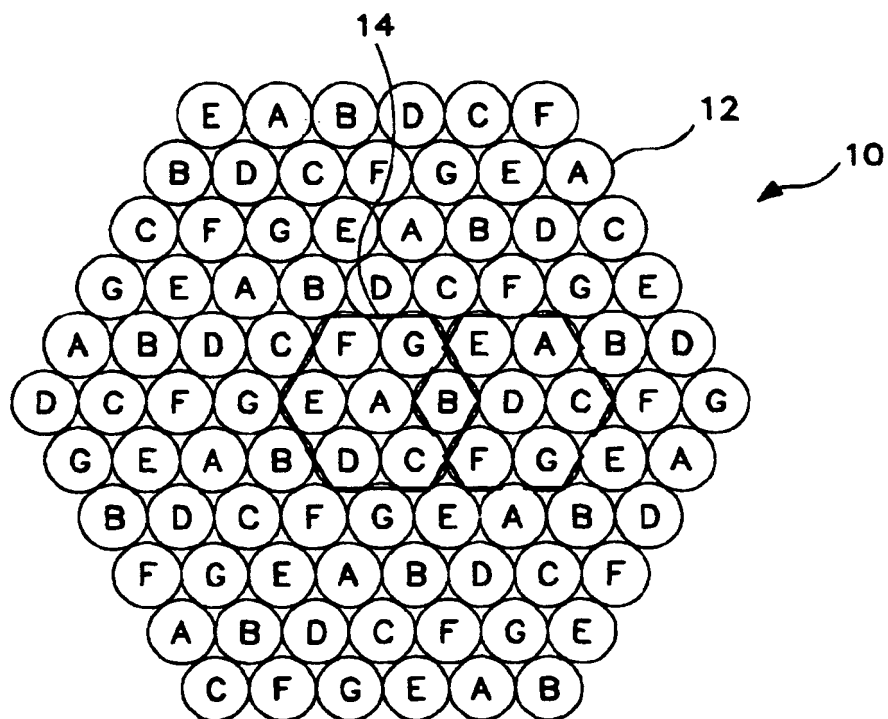jamming signal and weight the pixel beams.

FIG. 1

FIG. 2

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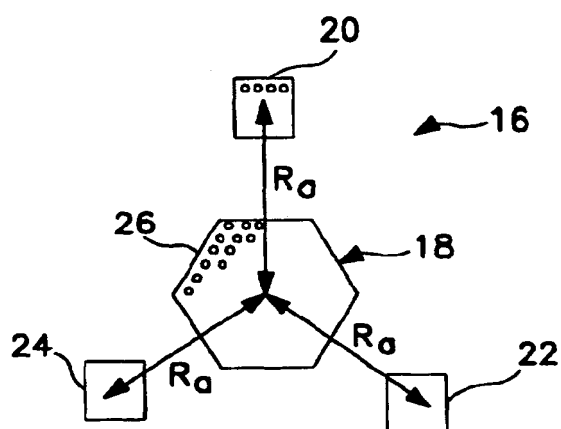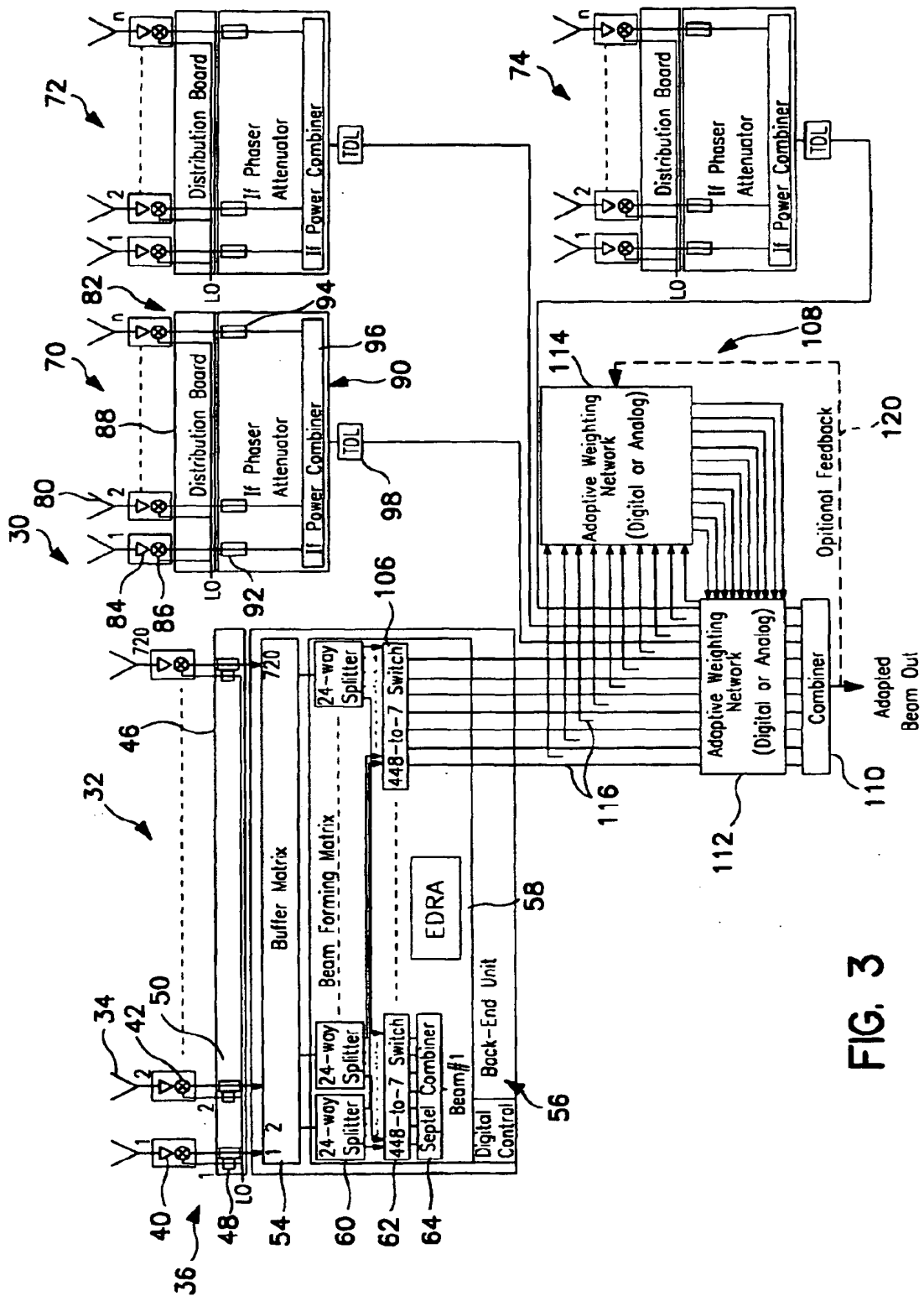FIG. 3

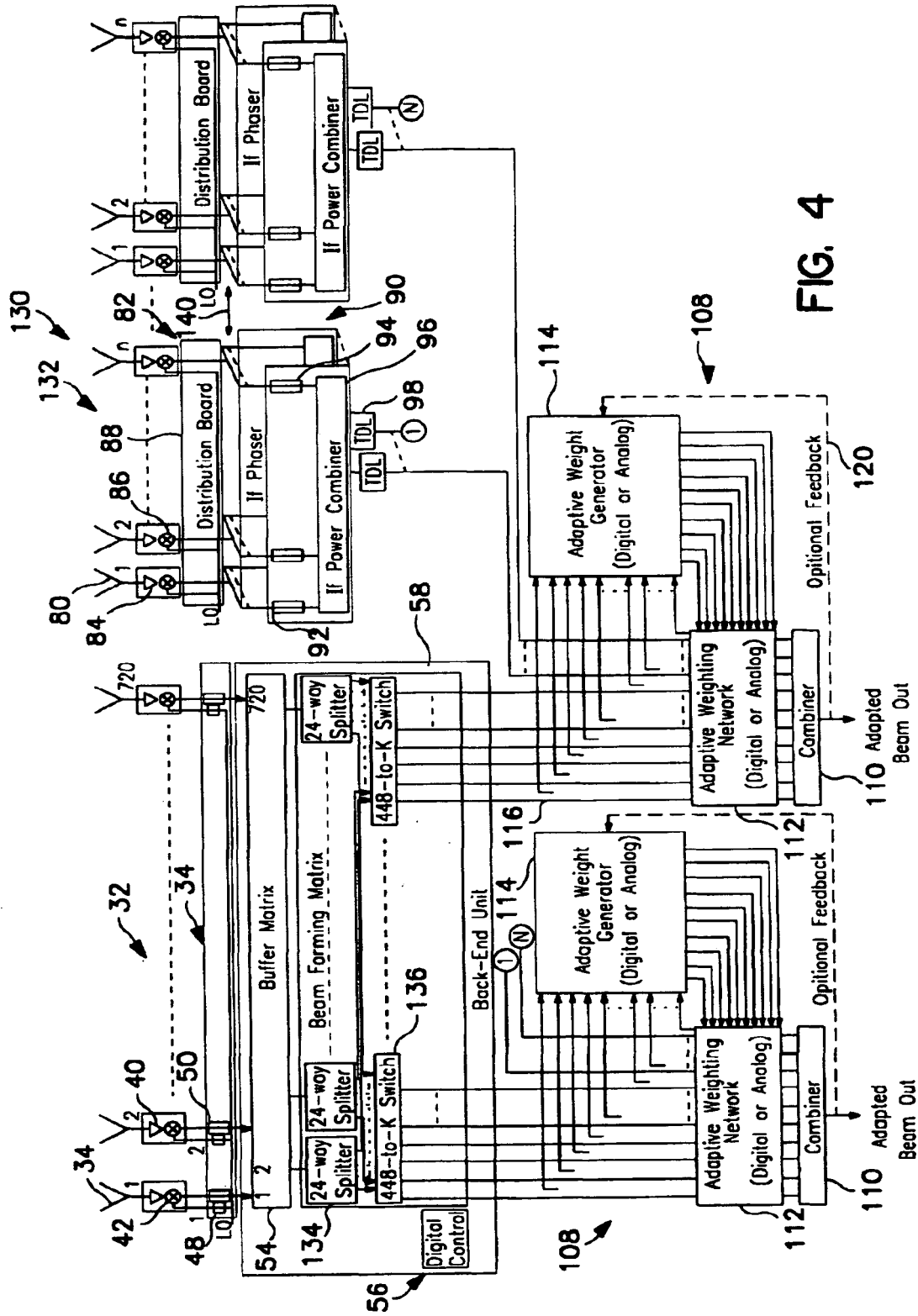FIG. 4